實驗二 ARM Assembly I

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1. 實驗目的

熟悉基本 ARMv7 組合語言語法使用。

在這次實驗中需要同學了解

- 如何利用條件跳躍指令完成程式迴圈的操作
- 算數與邏輯操作指令使用
- 暫存器(Register)使用與基本函式參數傳遞
- 記憶體與陣列存取
- Random Number Generator 使用 (加分)
- FPU instructions 使用 (加分)

2. 實驗原理

請參考上課 Assembly 部分講義。

3. 實驗步驟

3.1. Hamming distance

計算兩個數長度為 half-word(2bytes)的漢明距離，並將結果存放至 result 變數中。

Please calculate the Hamming distance of 2 half-word (2 bytes) numbers, and store the result into the variable “result”.

```
.data
    result: .byte 0
.text
    .global main
      .equ X, 0x55AA
      .equ Y, 0xAA55

hamm:
    //TODO
    bx lr
main:
    movs R0, #X //This code will cause assemble error. Why? And how
to fix.
    movs R1, #Y
    ldr R2, =result
    bl hamm
L: b L
```

Note: 漢明距離主要是利用 XOR 計算兩數 bit 間差異個數，計算方式可參考下

列連結。

Note: Hamming distance is basically using the XOR function to calculate the different number of “bits” of two numbers. Please check the following link for more information.

Reference: https://en.wikipedia.org/wiki/Hamming_distance

1. Problem definition and algorithm abstract

Hamming distance is the different bits between two numbers represented in binary.
e.g. 63=(111111)bin 64=(1000000)bin, then the Hamming distance is
0111111
1000000 distance = 7

It is a traditional bit manipulation problem.

The algorithm is as simple as just XOR (the instruction in ARM is EOR) the two number since once there is a different bit, XOR will make it be 1.

The ***c code*** is represented as follow

```c
int bitCount(unsigned int n)
{
    int counter = 0;
    while(n)
    {
        counter += n % 2;
        n >>= 1;
    }
    return counter;
}
```

Once the number has a bit, %2 will cause the remainder be 1, by this method we can accumulate it into the counter of counting the bits.

Finally, we >>= the number again and again till it reaches 0.

The ARM assembly is represented as follow

```
hamm:
  //TODO
  eor R0, R0, R1 //xor for how many bits are 1
  add R4, R0, #0 //n=r0
```

```
whileloop:
    cmp R4, #0 //while(n)
    beq return

   // counter as r3, the result of n%2 (which is the same as n&1)
save at R5
    and R5, R4, #1 //R5 for increment value in R3
    add R3, R3, R5 // counter+=n%2

    lsr R4 ,R4 ,#1 //n>>=1
    b whileloop

return:
 bx lr
```

2. Test cases tested

TEST1:

e.g. a=0x1000 =1000000000000
b=0x3f =0000000111111
a xor b =1000000111111 stored in r0

The correct answer should be 7, stored in r3.

Name	Value
r0	1000000111111 (Binary)
r1	63 (Decimal)
r2	536870912 (Decimal)
r3	7 (Decimal)

TEST2:

e.g. a=39 =0100111
b=125 =1111101
a xor b =1011010 stored in r0

The correct answer should be 4, stored in r3.

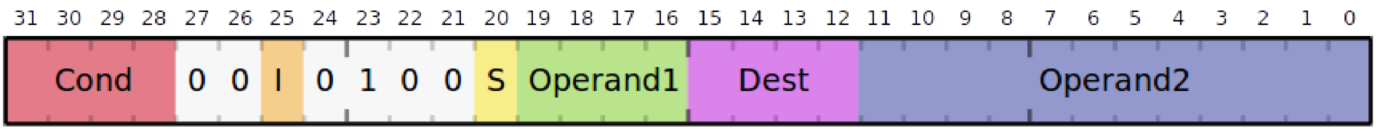
General Registers	
r0	1011010 (Binary)
r1	125 (Decimal)
r2	536870912 (Decimal)
r3	4 (Decimal)

3. About the error of 0x55AA and 0xAA55

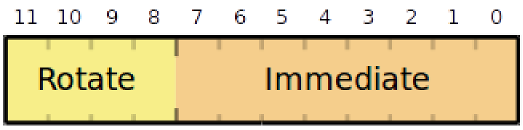
Reference link https://alisdair.mcdiarmid.org/arm-immediate-value-encoding/

The 0x55aa and 0xaa55 cannot be encoded by the method of link provided up, namely the ROTATING METHOD of using 12 bits immediate value (in ARM instruction architecture) to represent larger immediate value.

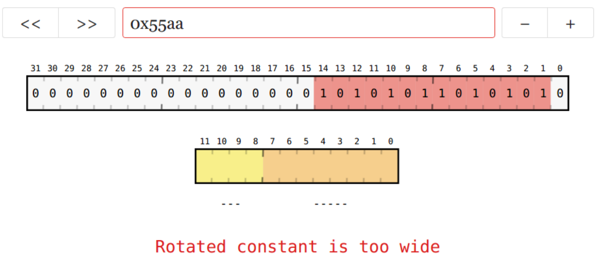
Here's the bit layout of an ARM data processing instruction:

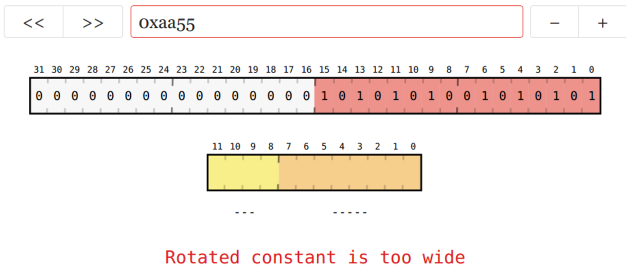


But ARM doesn't use the 12-bit immediate value as a 12-bit number. Instead, it's an 8-bit number with a 4-bit rotation, like this:



Which, in conclusion, cannot represent the value of 0x55aa and 0xaa55.





4. 4. Rethink of 3

Q: So how do we represented other values that are not accepted before?

A: Maybe we can use more register to represent then (by decomposition) move some accepted value to 2 or even more registers to add up (or some linear combinations) to form the unaccepted immediate value aforementioned.

3.2. Fibonacci serial

宣告一數值 N ($1 \le N \le 100$)，計算 Fib(N)並將回傳值存放至 R4 暫存器 Declare a number N($1 \le N \le 100$) and calculate the Fibonacci serial Fib(N). Store the result into register R4.

```
.text
    .global main
     .equ N, 20

fib:
    //TODO
    bx lr
main:
    movs R0, #N
    bl fib
L: b L
```

Note: 回傳值格式為 signed integer，若 Fib[N]結果 overflow 的話回傳-2, 當 N 數值出過範圍時 fib 回傳-1，計算方式可參考下列連結

Note: The returned value should be in signed integer format. If the result of Fib(N) overflows, you should return -2. If the value of N is outside the accepted range, you should return -1. Check the following link for more details of the calculation.

Reference: https://it.wikipedia.org/wiki/Successione_di_Fibonacci

1. Problem definition and algorithm abstract

The well-known mathematical sequence defined as below

The sequence F_n of Fibonacci numbers is defined by the recurrence relation:

$$F_n = F_{n-1} + F_{n-2},$$

with seed values[1][2]

$$F_1 = 1,\ F_2 = 1$$

or[5]

$$F_0 = 0,\ F_1 = 1.$$

(source Wikipedia)

In a nutshell, I write a checker named cmp_greater_than_1: and cmp_less_than100: to check if the input value is in the range, otherwise, minus r4 by 1 (r4 is originally initialized with 0) and return.

If it is really in the range, then go to Fibonacci main function, by using the loop method (the recursion may be too difficult to implement in ARM assembly)

Initialize the first →sec→fib, where fib=first+sec

Then move the 3 continuous numbers forward till reaches end.

By using the cmp, we may get the result of cmp value to branch, acquiring the method of conditional move like if/else or looping condition check in C.

Finally, a BVS instruction, which means BRANCH IF OVERFLOW SET

SIGNED.

Since we use adds, the Z V C N flags in ARM assembly will be updated and this BVS can successfully get flags with an eye to determining whether to branch or not.

The rest of detailed algorithm concepts have been written in the comments of the source code.

```
fib:
   //TODO
   //check if N is in the range, let r4= -1 for OUT_OF_RANGE
   cmp_greater_than1:
      cmp r0, #1
      bge cmp_less_than100
      //if OUT_OF_RANGE
      movs r4, #0
      sub r4, r4, #1
      b return

   cmp_less_than100:
      cmp r0, #100
      ble fibonacci_main
      //if OUT_OF_RANGE
      movs r4, #0
      sub r4, r4, 1
      b return //br for better manipulation??

     fibonacci_main:

      movs r4, #1 //first prototype for special-testcase judge

      cmp r0, #1 //fibonacci f(1)=1 --> 1 1 2 3 5 8 13...
      beq return
      cmp r0, #2
      beq return

      movs r1, #1 //first
      movs r2, #1 //second
```

```
	movs r4, #0 //fib(n)

	movs r5, #2 //fibonacci counnter start at 2 (modification for overflow detection)

      for_loop:
	adds r4, r1, r2  //third=fir+sec adds will update the flag!! FOR SURE
	movs r1, r2 //fir=sec
	movs r2, r4//sec=third

	add r5, r5, #1//increment the counter by 1

	bvs overflow_return //f(48)will cause overflow in 32bit intege

	 cmp r5, r0 //compare if it is still in the fib range
	blt for_loop//back to loop again

    return:
	bx lr

    overflow_return:
	movs r4, #0
	subs r4, r4, #2
	bx lr
```

2. **Test cases tested**

(1) f(46) = 1836311903

r4	1836311903 (Decimal)
r5	46

45 : 1134903170 = 2 x 5 x 17 x 61 x 109441
46 : 1836311903 = 139 x 461 x 28657
47 : 2971215073

(2) f(47) exceeds the value of 2^31-1 can represents so we set r4 = -2

r4	-2 (Decimal)	
r5	47	

(3) f(200) is not in the range

General Registers		General Purpose and FPU Register
r0	220 (Decimal)	
r1	1068 (Decimal)	
r2	536872044 (Decimal)	
r3	0	
r4	-1 (Decimal)	

Does not store in r0, directly back to main (r5 will be only stored in Fibonacci main function)

3. Overflow detection

Mentioned above with BVS instruction and its explanation.

Reference: https://community.arm.com/processors/b/blog/posts/condition-codes-1-condition-flags-and-codes

4. Problem encountered and solutions

(1) I first found that the bvs instruction was in vain, nonetheless it turned out to be that add was used instead of adds, only the adds will update the Z C V N flags in arm architecture.

(2) bvs by branching if a register is overflow, once a register exceeds 2^31-1(and in Fibonacci is f(47)) the overflow flag should be set and set r4 to be -2.

However, I originally set the group of 3 numbers in the order of fib, fir, sec where sec=fib+fir. Problem is that even though fib is only f(45), sec will be f(47)

The V flag will still be set, causing the r4 value to be -2, which is totally wrong.

So I debug by using the order of fir sec fibo, where fibo=fir+sec, once the fibo reaches the f(47) it triggers the flag and cause the bvs to branch, terminating the Fibonacci function and set r4=-2.

3.3. Bubble sort

利用組合語言完成長度為 8byte 的 8bit 泡沫排序法。

Please implement the Bubble sort algorithm for the 8 bytes data array with each element in 8bits by assembly.

實作要求：完成 do_sort 函式，其中陣列起始記憶體位置作為輸入參數 R0，程式結束後需觀察 arr1 與 arr2 記憶體內容是否有排序完成。

Implementation Requirement: Fill-in the do_sort function. The start address of the array is store in the R0 register. Observe the result of arr1 and arr2 in the memory viewer after calling the do_sort functions. The two arrays should be sorted.

```
.data
     arr1: .byte 0x19, 0x34, 0x14, 0x32, 0x52, 0x23, 0x61, 0x29
     arr2: .byte 0x18, 0x17, 0x33, 0x16, 0xFA, 0x20, 0x55, 0xAC
.text
    .global main
do_sort:
    //TODO
    bx lr
main:
    ldr r0, =arr1
    bl do_sort
    ldr r0, =arr2
    bl do_sort
L: b L
```

Note: 注意記憶體存取需使用 byte alignment 指令，例如：STRB, LDRB

Note: The memory access may require the instructions that support byte-alignment, such as STRB, LDRB.

1. **<u>Problem definition and algorithm abstract</u>**

Bubble sort, sometimes referred to as sinking sort, is a simple sorting algorithm that repeatedly steps through the list to be sorted, compares each pair of adjacent items and swaps them if they are in the wrong order.

Pseudo Code Implementation:

```
void bubble_sort(int arr[], int len)
{
    int i, j, temp;
    for (i = 0; i < len - 1; i++)
        for (j = 0; j < len - 1 - i; j++)
            if (arr[j] > arr[j + 1])
                    {
                temp = arr[j];
                arr[j] = arr[j + 1];
                arr[j + 1] = temp;
```

```
            }
}
```

The ARM assembly is represented as follow

More detailed code explanations have been written in the comments part.

```
do_sort:
   //TODO arr from 0 to 7

   movs r3, #7 //i<len-1-i part
   movs r1, #0 //int i=0
   for_loop_outer: //i=[0,6]

   movs r2, #0 //int j=0
   sub r9, r3, r1//len-1-i
      for_loop_inner:
         add r4, r0, r2 //offset in byte get arr+j address, store in
r4
         ldrb r5, [r4]//dereference to get value r5 as arr[j]

         add r6, r4, #1 //offset in byte get arr+j address ,store in
r6
         ldrb r7, [r6]

         cmp r5,r7
         blt swap
         swap_is_done:
         //j++ then j<len-1-i
         add r2, r2, #1
          //r9 as len-1-i r9 = r3(7 which is len-1 )- r1 (which is i)
         cmp r2,r9
         blt for_loop_inner

   //i++ then i< len -1
   add r1, r1, #1
   cmp r1, #7
   blt for_loop_outer
```

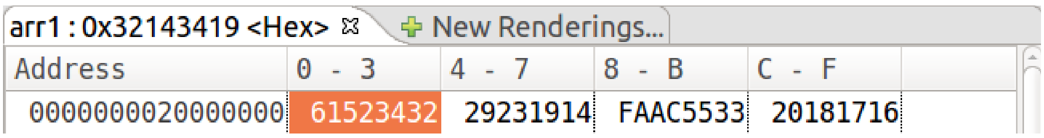
```
    b return //job is done

    swap:  //using r8 as temp value for swapping use STRB for
storing in memory
        movs r8, r5
        movs r5, r7
        movs r7, r8

        //store the fucking value back in memory
        strb r5, [r4]
        strb r7, [r6]
        b swap_is_done

        return:
        bx lr
```

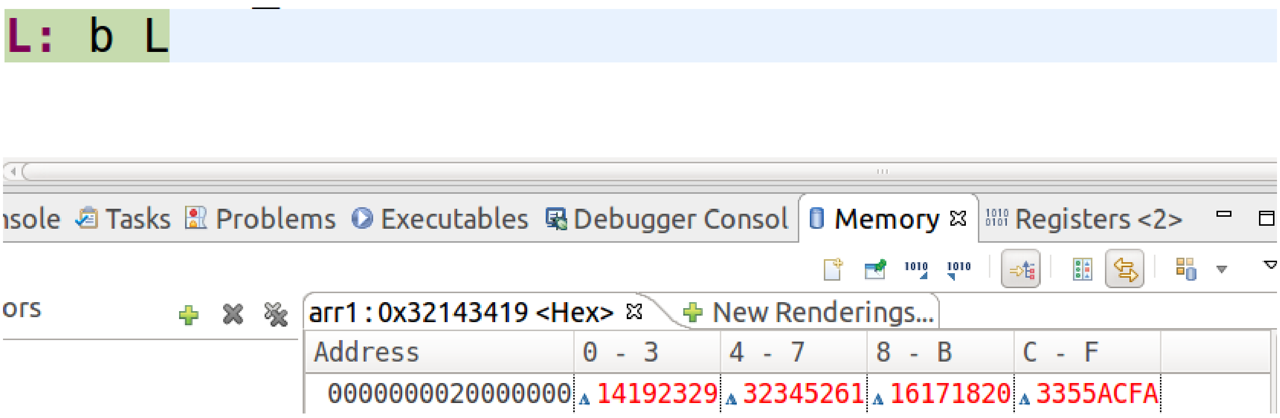
2. Result

Since the data store is 0x_ _ which is a byte, so it fits perfectly into the memory block where a block is 4 bytes (a memory row is 4*4=16 bytes), so we can easily see the array are successfully sorted descending.

Address 0x20000000~0x20000007 stores arr1 and 0x20000008~0x2000000F stores arr2.

Or sorting in ascending order by bgt





3. Problem encountered and solutions

(1) Originally the program terminated immediately after swap, and it turned out that I should back to the loop using branch rather than writing nothing, otherwise, the program will keep going to the end.

```
swap:  //using r8 as temp value for swapping use STRB for
storing in memory

        movs r8, r5
        movs r5, r7
        movs r7, r8

        //store the fucking value back in memory
        strb r5, [r4]
        strb r7, [r6]
      b swap_is_done(without this, program will keep going till
return (bx lr to main funtion), through this error, I realize
that the  ARM assembly is executing in sequence order)
```

(2) There are i and j , j is in the inner loop, once the inner loop terminated, j should be reset to 0. I once forgot to do this and the memory pointer went so far away to arr2 , causing the result error.

```
for_loop_outer: //i=[0,6]

    movs r2, #0 //int j=0
    sub r9, r3, r1//len-1-i
```

for_loop_outer: Had it been the C code, it may cause the segmentation fault of ERROR_OUT_OF_RANGE

3.4. Monte-Carlo Method for Estimating Pi with FPU and RNG (加分題 10%)(Optional problems with additional 10% score)

透過 STM32L476 晶片上面的 Random Number Generator 硬體來產生亂數，並結合 FPU 使用進一步估算 Pi 的值

Using the Random Number Generator hardware on STM32L476 to generate numbers for estimating the value of Pi by using the FPU.

3.4.1 Enabling FPU (Floating Point Unit) and Floating Point Manipulation

請參考 M4 programming manual.pdf 來開啓 FPU 計算功能，並進行下列運算

Please check the M4 programming manual to enable the functionality of FPU and do the following calculation.

```
  .syntax unified
  .cpu cortex-m4
  .thumb
.data
  x: .float 0.123
  y: .float 0.456
  z: .word 20
.text
  .global main

enable_fpu:
  //Your code start from here

  bx lr

main:
  bl enable_fpu
  ldr r0,=x
  vldr.f32 s0,[r0]
  ldr r0,=y
  vldr s1,[r0]
  vadd.f32 s2,s0,s1
  // Your code start from here
  //Calculate the following values using FPU instructions
  //and show the register result in your report

  // s2=x-y
  // s2=x*y
  // s2=x/y

  // load z into r0,
  // copy z from r0 to s2,
  // convert z from U32 to float representation F32 in s2
  // calculate s3=z+x+y
L: b L
```

Q3.4.1.1: 如果 enable_fpu 留空，程式會停在哪裡？為什麼？ If the enable_fpu function is empty in the above code, where will the program stop at and why?

Program will halt at this line vldr.f32 s0,[r0], which is the very first code to use the floating point instruction.

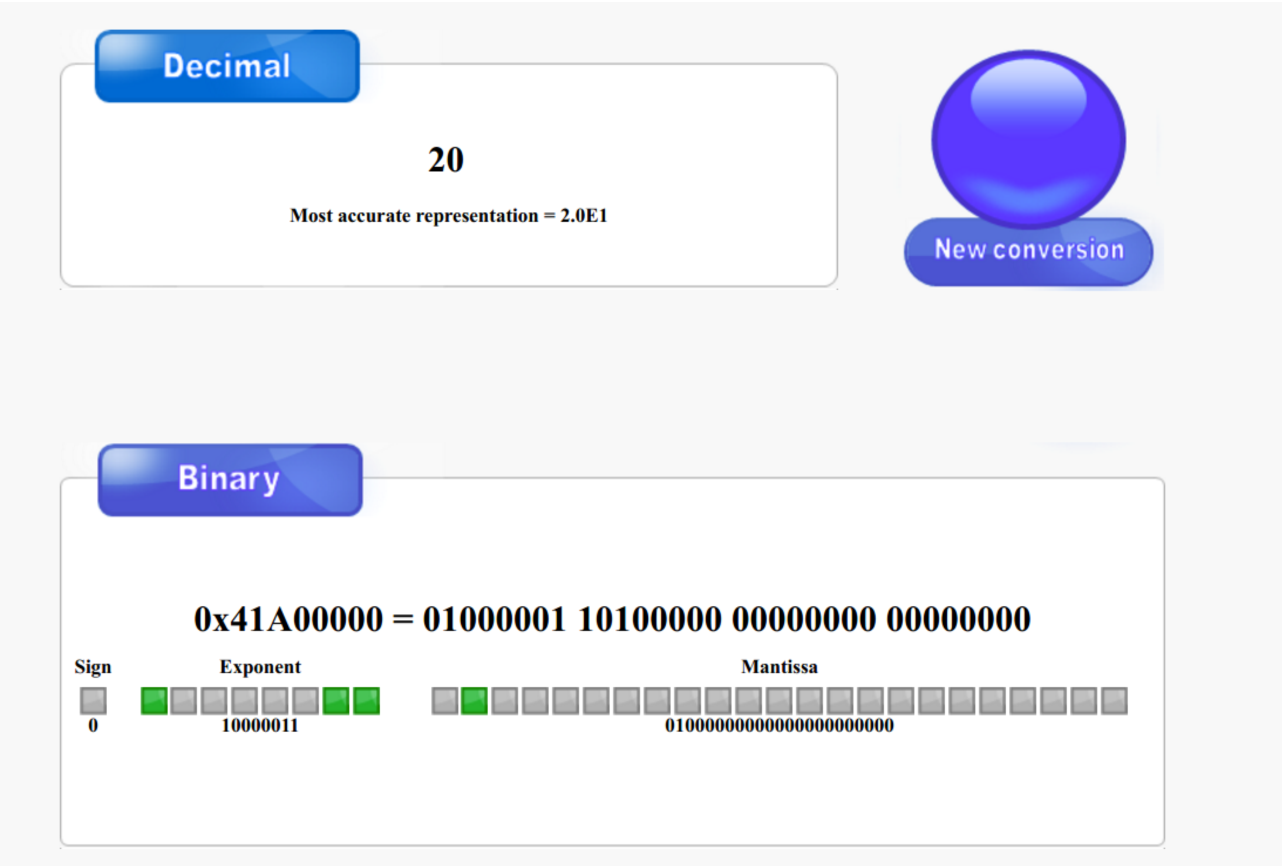
To be more specific and precise, it will halt at line96 of startup_stm32, b infinite_loop to search for something to cope with floating point, but nothing is there.

So the program, in fact, search nothing and halt there.

Q3.4.1.2: 為什麼需要將 U32 轉成 F32 格式再相加？如果想直接 load 一個值代表 20 到 s2 中不需轉換就能運算，應該將 z 修改成多少才能得到相同答案？
Why do we need to convert the U32 to F32 format before the addition? If we want to directly load a value represents 20 for calculation without further format conversion, what value should we modify to z in order to get the same answer?

We need the pseudo type conversion since the s2 is still not the REAL FLOAT TYPE. (IEEE754 is the correct type) so we need TYPE CONVERSION from int to float.

If we want to directly use it, we should do it according to IEEE754 and represent it in binary



0x41A00000 = 01000001 10100000 00000000 00000000

will be correct (+) (1+2^-2)*2^(131-127)=1.25*16=20(float)

3.4.2 Random Number Generator

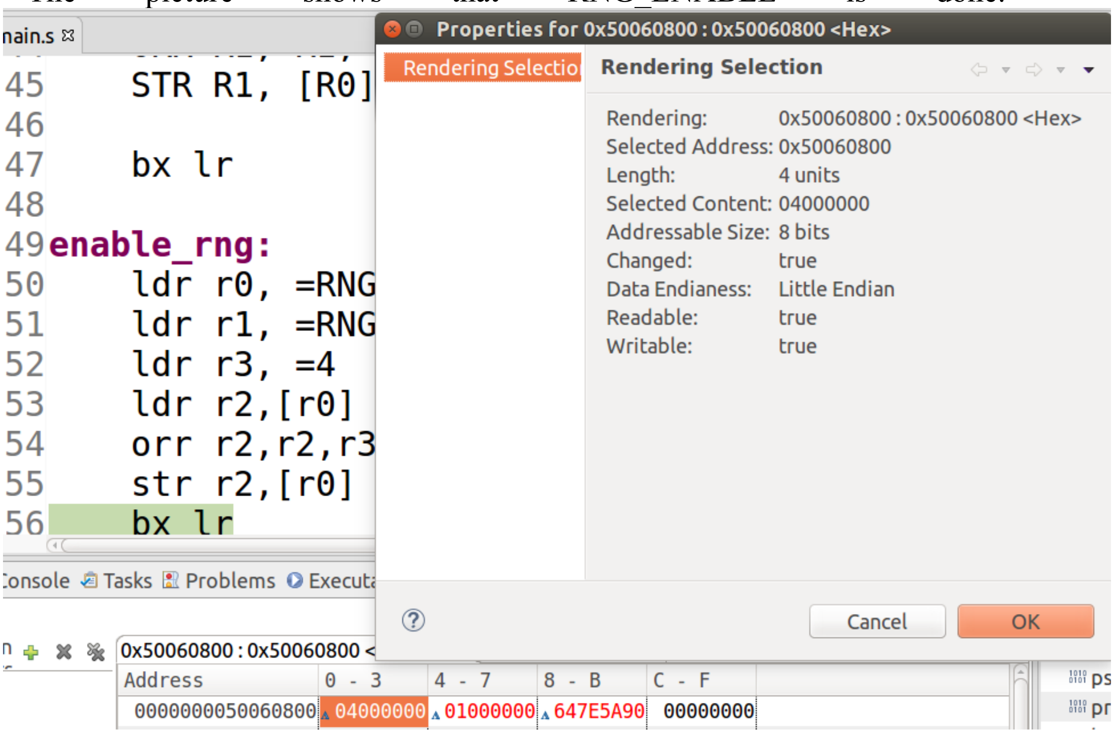
開啓 RNG 功能，產生一組(x,y)點在單位平面裡.

Enable the functionality of RNG and generate a sample point in the unit area.

```
   .syntax unified
   .cpu cortex-m4
   .thumb
.text
   .global main
   .equ RCC_BASE,0x40021000
   .equ RCC_CR,0x0
   .equ RCC_CFGR,0x08
   .equ RCC_PLLCFGR,0x0c
   .equ RCC_CCIPR,0x88
   .equ RCC_AHB2ENR,0x4C
   .equ RNG_CLK_EN,18

   // Register address for RNG (Random Number Generator)
   .equ RNG_BASE,0x50060800 //RNG BASE Address
   .equ RNG_CR_OFFSET,0x00 //RNG Control Register
   .equ RNGEN,2 // RNG_CR bit 2

   .equ RNG_SR_OFFSET,0x04 //RNG Status Register
   .equ DRDY,0 // RNG_SR bit 0
   .equ RNG_DR_OFFSET,0x08 //RNG Data Register (Generated random
number!)
   //Data Settings for 3.4.4
   .equ SAMPLE,1000000

set_flag:
   ldr r2,[r0,r1]
   orr r2,r2,r3
   str r2,[r0,r1]
   bx lr

enable_fpu:
   //Your code in 3.4.1

   bx lr

enable_rng:
   //Your code start from here
   //Set the RNGEN bit to 1

   bx lr

get_rand:
   //Your code start from here
   //read RNG_SR
   //check DRDY bit, wait until to 1
   //read RNG_DR for random number and store into a register for
later usage

   bx lr

main:
```

```
//RCC Settings
   ldr r0,=RCC_BASE
   ldr r1,=RCC_CR
   ldr r3,=#(1<<8) //HSION
   bl set_flag
   ldr r1,=RCC_CFGR
   ldr r3,=#(3<<24) //HSI16 selected
   bl set_flag
   ldr r1,=RCC_PLLCFGR
   ldr r3,=#(1<<24|1<<20|1<<16|10<<8|2<<0)
   bl set_flag
   ldr r1,=RCC_CCIPR
   ldr r3,=#(2<<26)
   bl set_flag
   ldr r1,=RCC_AHB2ENR
   ldr r3,=#(1<<RNG_CLK_EN)
   bl set_flag
   ldr r1,=RCC_CR
   ldr r3,=#(1<<24) //PLLON
   bl set_flag
chk_PLLON:
   ldr r2,[r0,r1]
   ands r2,r2,#(1<<25)
   beq chk_PLLON

//Your code start from here
//Enable FPU,RNG
//Generate 2 random U32 number x,y
//Map x,y in unit range [0,1] using FPU
//Calculate the z=sqrt(x^2+y^2) using FPU
//Show the result of z in your report
L:   b L
```

（1） The picture shows that RNG_ENABLE is done.



（2） The picture shows that 2 random numbers x for r3 and y for r4 respectively have been successfully generated.

r2	510723046 (Decimal)
r3	2100797682
r4	510723046 (Decimal)

(3) using vcvt.f32.s32 and vabs.f32 to firstly convert the data in int into float then using abs to get the absolute value for mapping in the future.

s2	2147483648 (Decimal)
s3	2100797696 (Decimal)
s4	510723040

Inaccuracy is due to IEEE 754 floating point standard if the data exceeded the 23 bit in floating point representation.

單精度二進制小數，使用 32 個位元存儲。

1	8	23 位長
S	Exp	Fraction
31	30 至 23 偏正值 （實際的指數大小+127）	22 至 0 位編號（從右邊開始為 0）

(4) Mapping it into [0,1] by dividing by INT_MAX = 2^32-1 (since the number generated is in SIGNED FORMAT)

s2	2147483648 (Decimal)
s3	0.978260159
s4	0.237823948

(5) Sum z(s5)=x(s3)^2+y(s4)^2 and get sqrt(z)

s3	0.956992924
s4	0.0565602295
s5	1.01355314

s2	2147483648 (Decimal)
s3	0.956992924
s4	0.0565602295
s5	1.0067538

Inaccuracy due to IEEE 754

3.4.3 Estimation of Pi

使用 Monte Carlo Method 來估算 Pi 的值

Using Monte Carlo Method to estimate the value of Pi.

Note:

1. Report 中請至少附上三次使用一百萬個點估算完的 Pi 值的 register 結果截圖

   Please attach the screenshots of the register for at least 3 estimation results using 1 million sample points.

2. 請使用 3.4.2 的程式模板進行修改，以避免修改到 RCC 設定影響 RNG 功能

   Please use the code template provided in 3.4.2 for this problem. RNG may raise error if the settings of RCC are incorrect.

Reference : http://www.eveandersson.com/pi/monte-carlo-circle

<u>Results:</u>

pi=4*inner_point_cnt/sample_cnt, tried 3 times

s5	1000000
s6	3.14003205

s6	3.14119196

s6	3.14272809